

Open X-ray tomography data and code from the Helsinki lab

Samuli Siltanen

Numerical methods for Computed Tomography:
Scientific innovations & industrial challenges

Bologna, Italy

January 26, 2023



Instagram:
@samuntiede
@monday_spider



YouTube:
@professor_sam
@Samuntiedekanava

This my industrial-academic background



2009: Professor, University of Helsinki, Finland



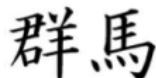
2006: Professor, Tampere University of Technology, Finland



2005: R&D scientist at Palodex Group



2004: R&D scientist at GE Healthcare



2002: Postdoc at Gunma University, Japan

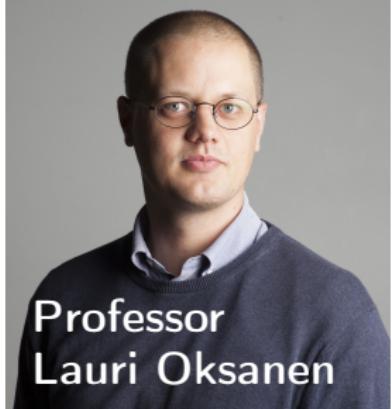


2000: R&D scientist at Instrumentarium Imaging



1999: PhD, Helsinki University of Technology, Finland

We have a research group of roughly 30 people
at University of Helsinki



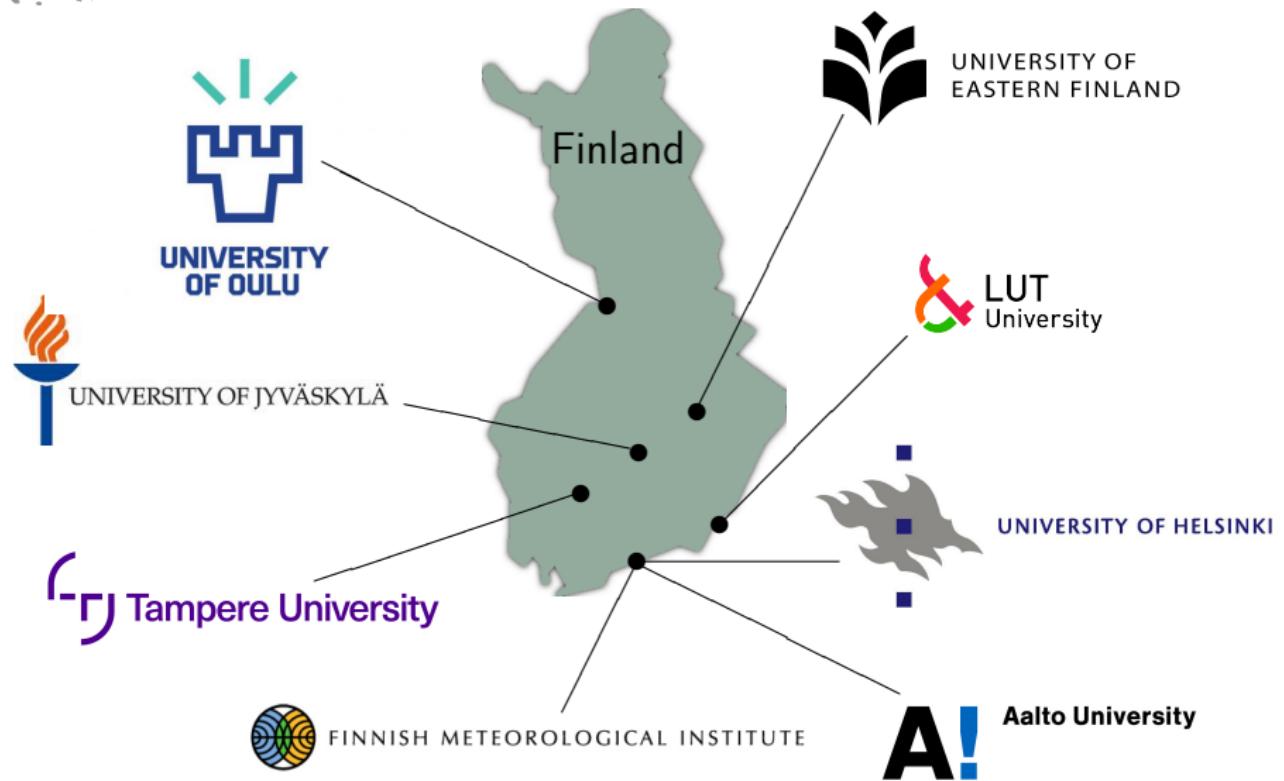


Finnish Centre of Excellence in Inverse Modelling and Imaging

2018-2025



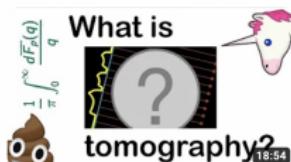
CENTRES OF EXCELLENCE
IN RESEARCH



Samun tiedekanava



7 231 subscribers, 295 000 views, <https://youtube.com/@Samuntiedekanava>



What is tomography?

23K views • 2 years ago



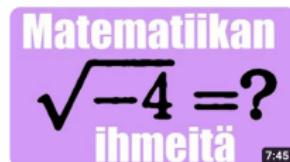
Mathematical modelling: How does a virus spread in a population?

21K views • 2 years ago



Wonders of Mathematics: Matrices

16K views • 3 years ago



Wonders of Mathematics: Complex numbers

11K views • 4 years ago



Wonders of mathematics: Infinity

11K views • 3 years ago



Sam's Science Splash: Fish Removal

7.3K views • 5 years ago



Wonders of mathematics: Fourier series

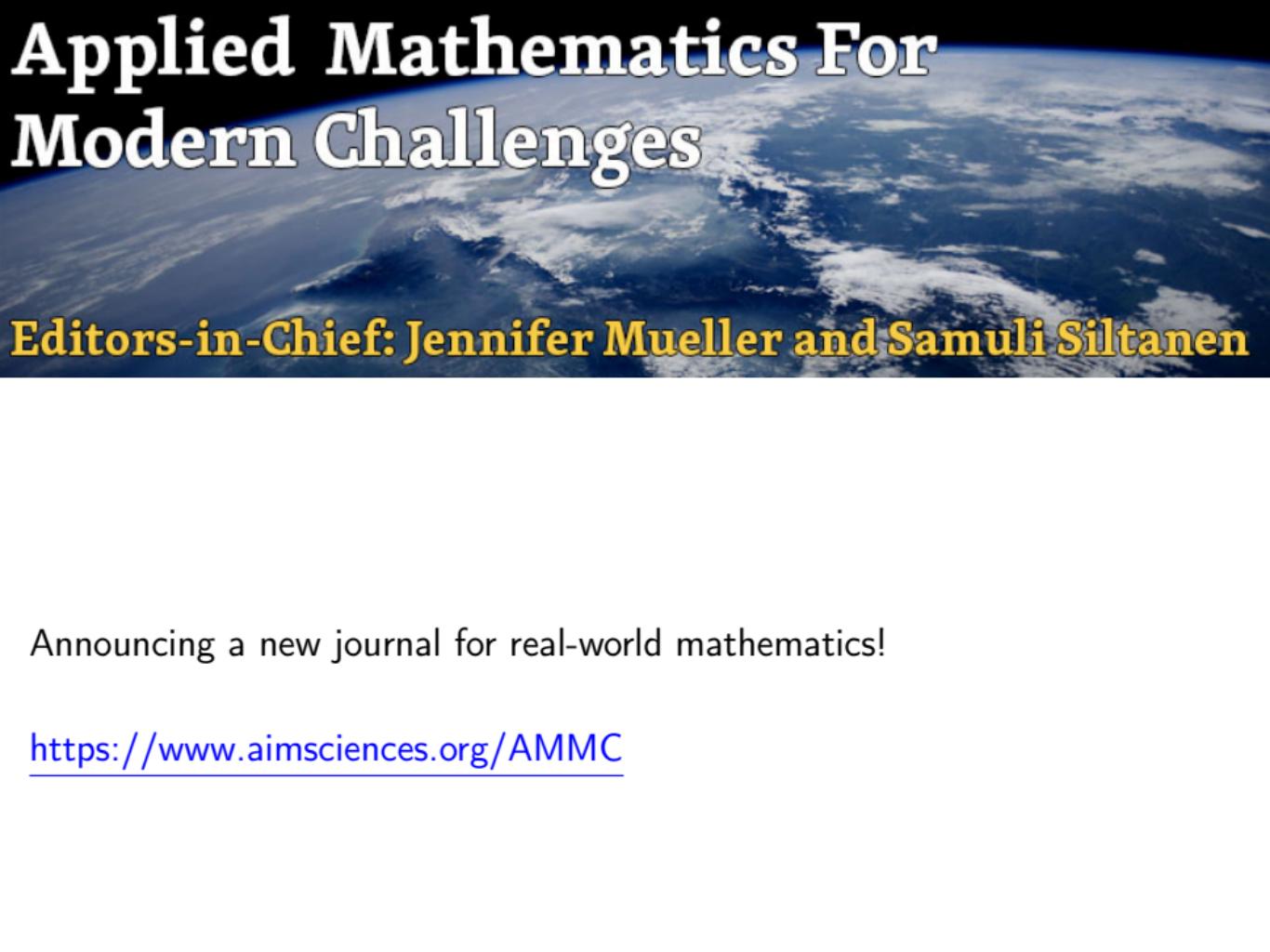
6.8K views • 2 years ago



Samun tiedepläjäys: Nopianhteito ja todennäköisyyden luonne

6.4K views • 5 years ago

Applied Mathematics For Modern Challenges



Editors-in-Chief: Jennifer Mueller and Samuli Siltanen

Announcing a new journal for real-world mathematics!

<https://www.aimsce...>[AMMC](https://www.aimsce...)

Outline

X-ray imaging and the Helsinki lab

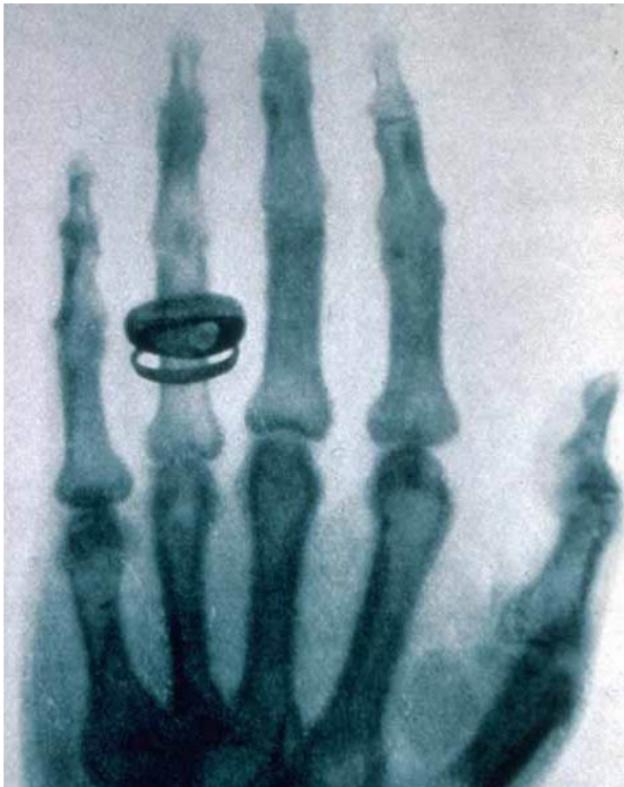
Datasets from the Helsinki lab

Dynamic X-ray datasets from the Helsinki lab

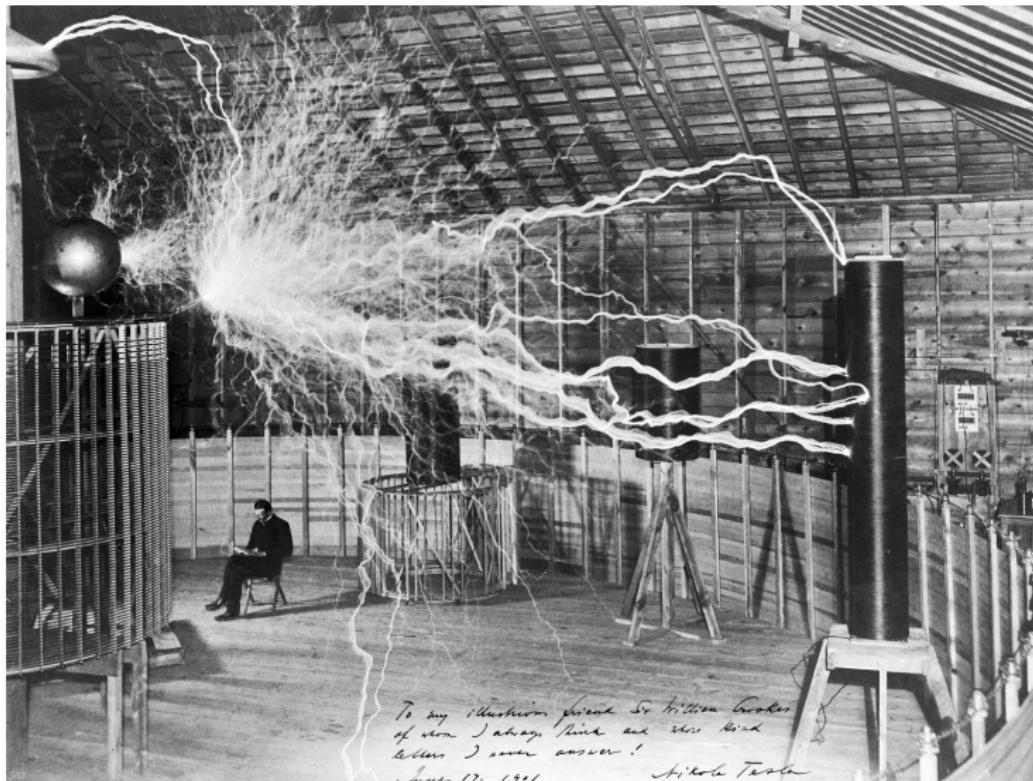
Helsinki tomography challenge 2022

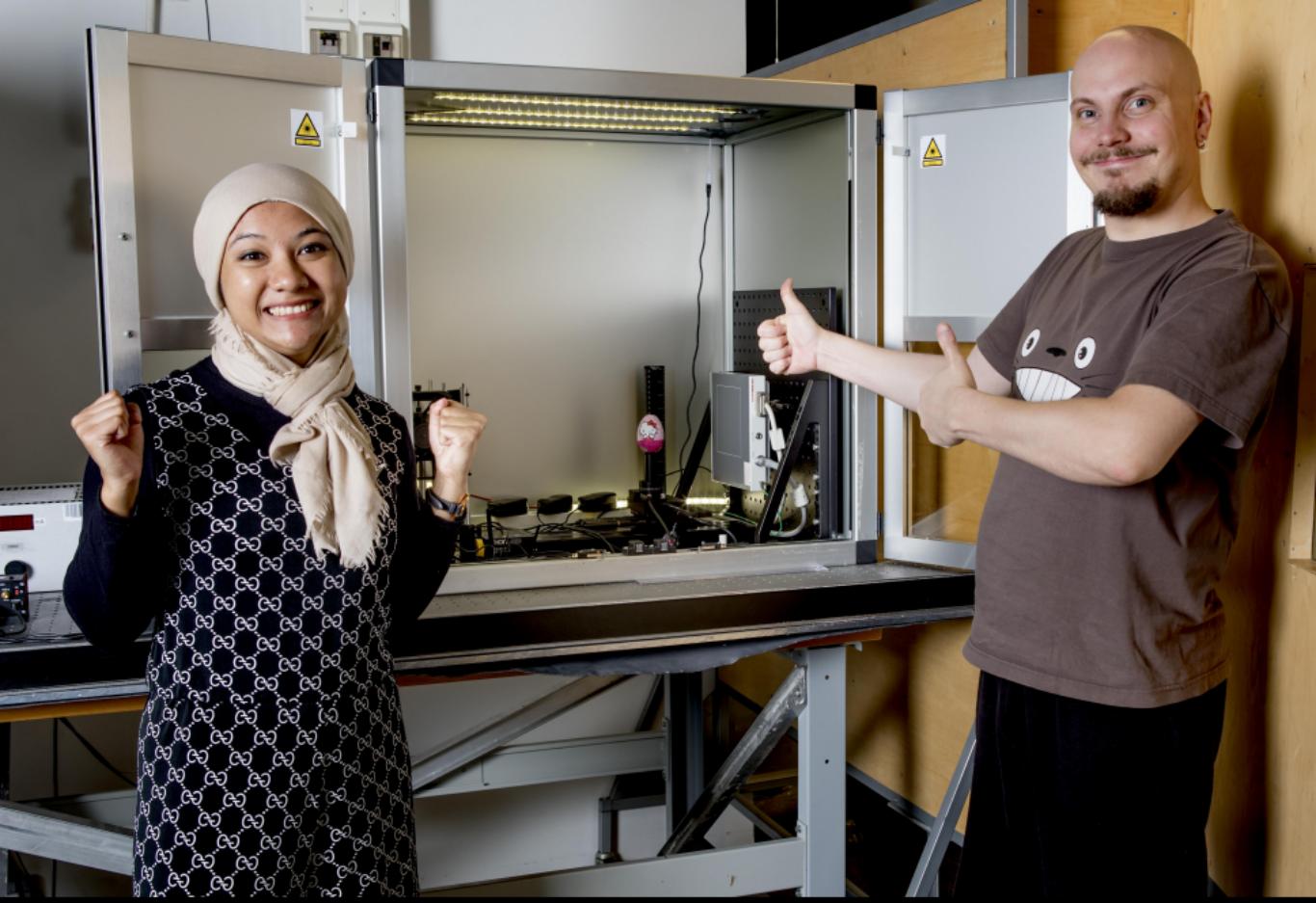
Bonus: Helsinki Deblur Challenge 2021

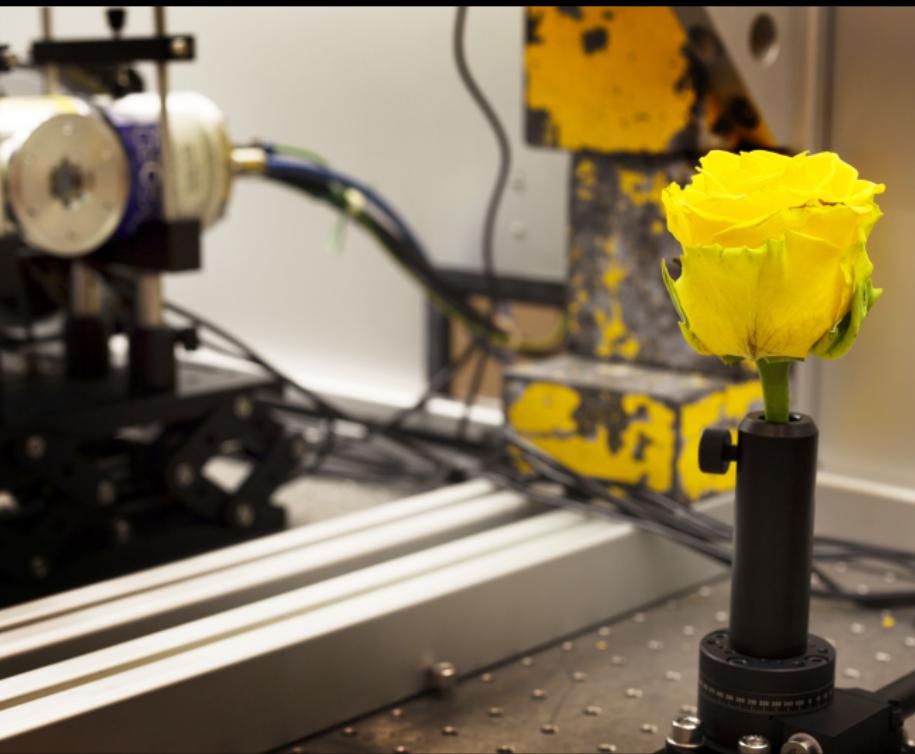
Wilhelm Conrad Röntgen invented X-rays and was awarded the first Nobel Prize in Physics in 1901



But even before Röntgen, Nikola Tesla had observed X-rays in his own way

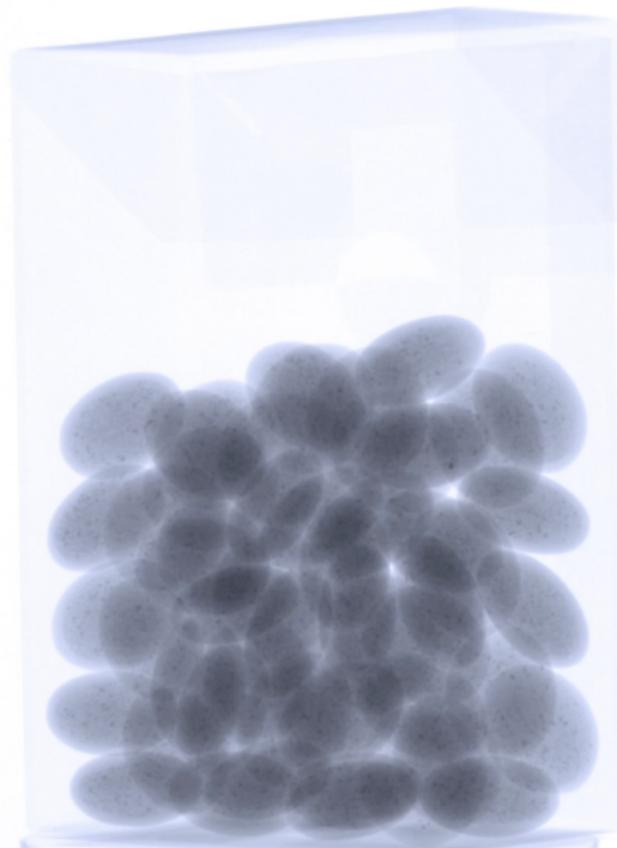








We can see through a box of candy!



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X-ray imaging and the Helsinki lab

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Helsinki tomography challenge 2022

Bonus: Helsinki Deblur Challenge 2021

Static X-ray datasets from the Helsinki lab

There are many datasets on this page:

<https://fips.fi/dataset.php>

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Bonus: Helsinki Deblur Challenge 2021



We construct a dynamic “emoji phantom” using small stones and stop-motion animation



Measurement:
Zenith Purisha

We construct a dynamic “emoji phantom” using small stones and stop-motion animation



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Measurement:
Zenith Purisha

The emoji dataset has been used in several papers

- ▶ Bubba T A, März M, Purisha Z, Lassas M and Siltanen S 2017, *Shearlet-based regularization in sparse dynamic tomography*. Wavelets and Sparsity XVII, Proc. of SPIE Vol. 10394, 103940Y
- ▶ Hakkarainen J, Purisha Z, Solonen A and Siltanen S 2019, *Undersampled dynamic X-ray tomography with dimension reduction Kalman Filter*. IEEE Transactions on Computational Imaging 5(3), pp. 492-501
- ▶ Gao, R., Tronarp, F., and Särkkä, S. (2019). *Iterated Extended Kalman Smoother-based Variable Splitting for L_1 -Regularized State Estimation*. IEEE Transactions on Signal Processing, 67(19), 5078-5092.
- ▶ Pasha, M., Saibaba, A. K., Gazzola, S., Espanol, M. I., and de Sturler, E. (2021). *Efficient edge-preserving methods for dynamic inverse problems*. arXiv preprint arXiv:2107.05727.

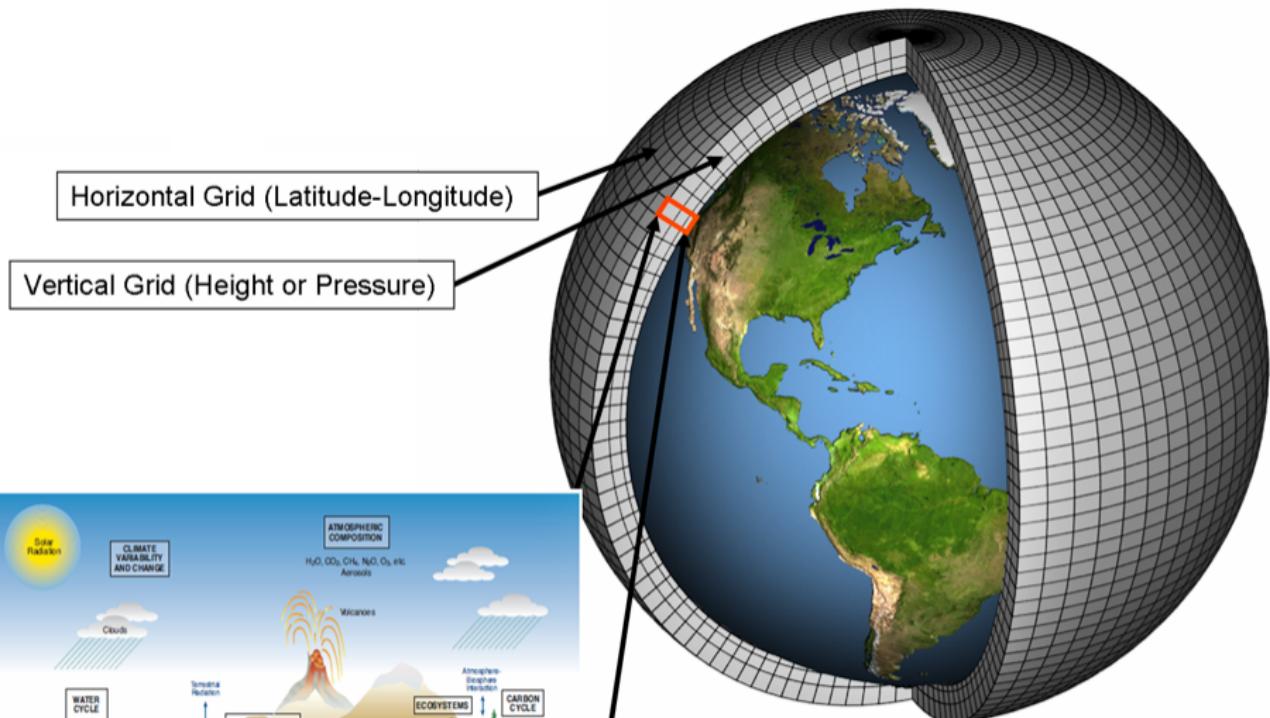
Plant metabolism dynamic phantom

You can find it on the page

<https://fips.fi/dataset.php>

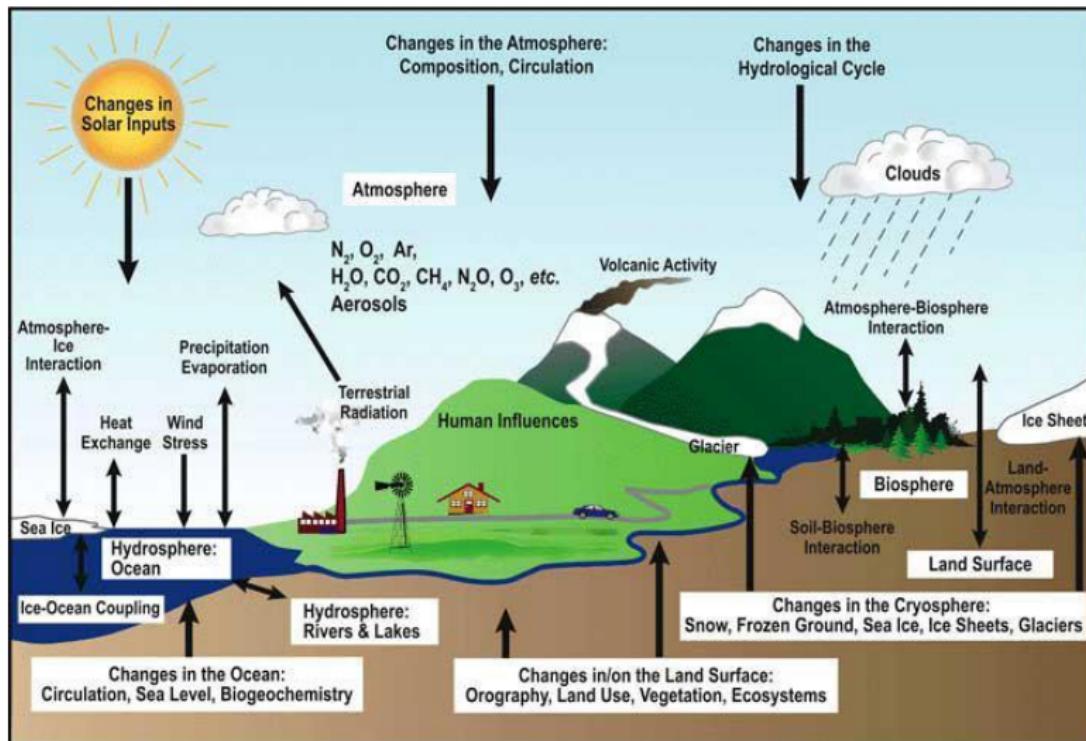
under the title “Gel phantom data for dynamic X-ray tomography”.

Climate change is predicted using climate models

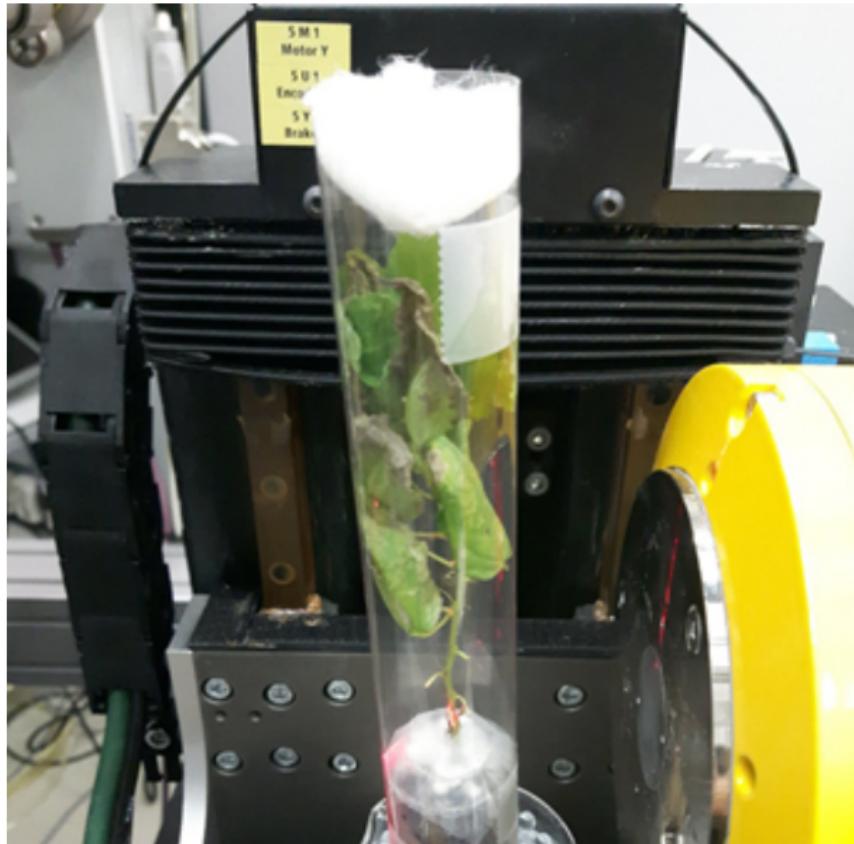


Source: Wikipedia

Climata models have a lot of details, and plant metabolism is crucial to model accurately

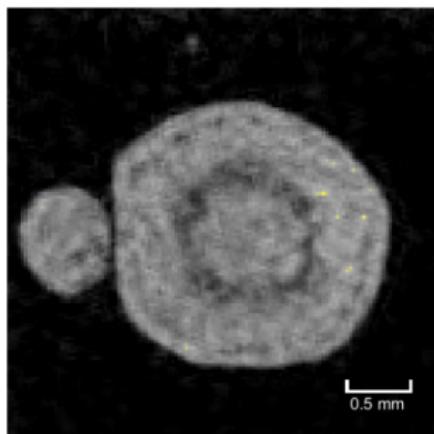


**Tomography study jointly with physicists,
biologists, radiochemists and climate scientists**

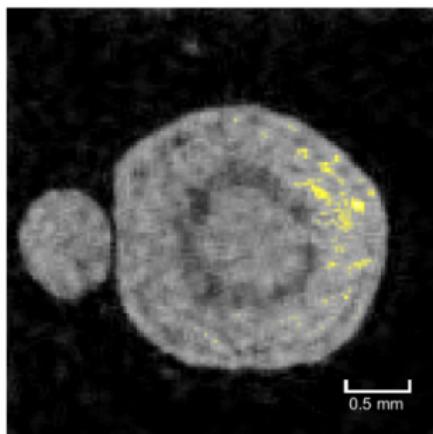


Time-dependent sparse tomography reveals the movement of iodine in the phloem

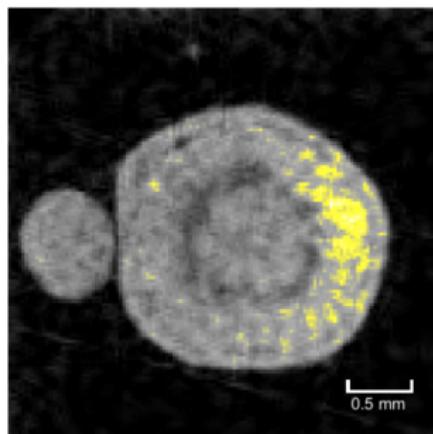
0 minutes



166 minutes



235 minutes



Motorized phantom by Tommi Heikkilä

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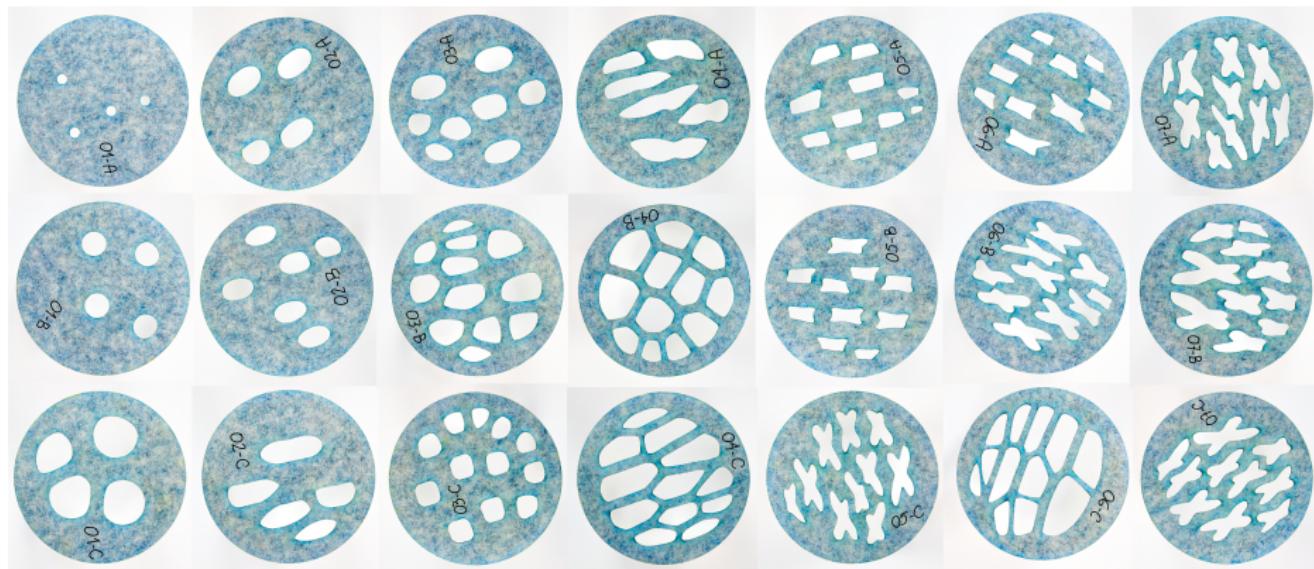
HTC2022

HELSINKI TOMOGRAPHY CHALLENGE

Check it out: <https://www.fips.fi/HTC2022.php>

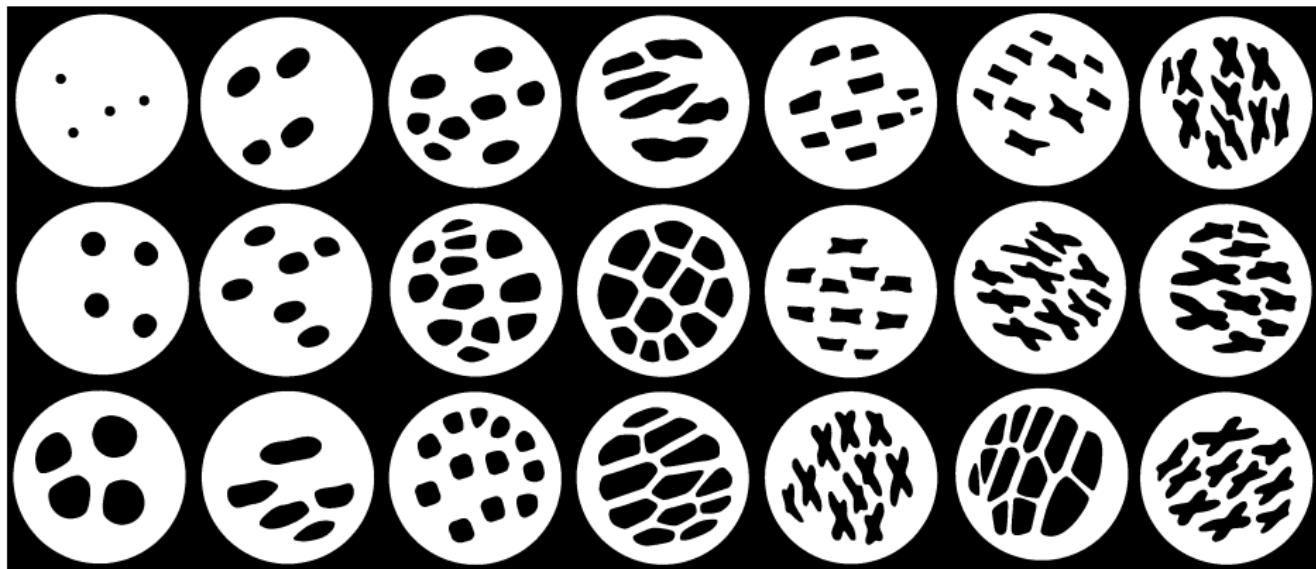
Challenge production team: Alexander Meaney, Fernando Moura,
Siiri Rautio, Salla Latva-Äijö, Tommi Heikkilä and S.

We made several plastic phantoms with differently shaped holes in them



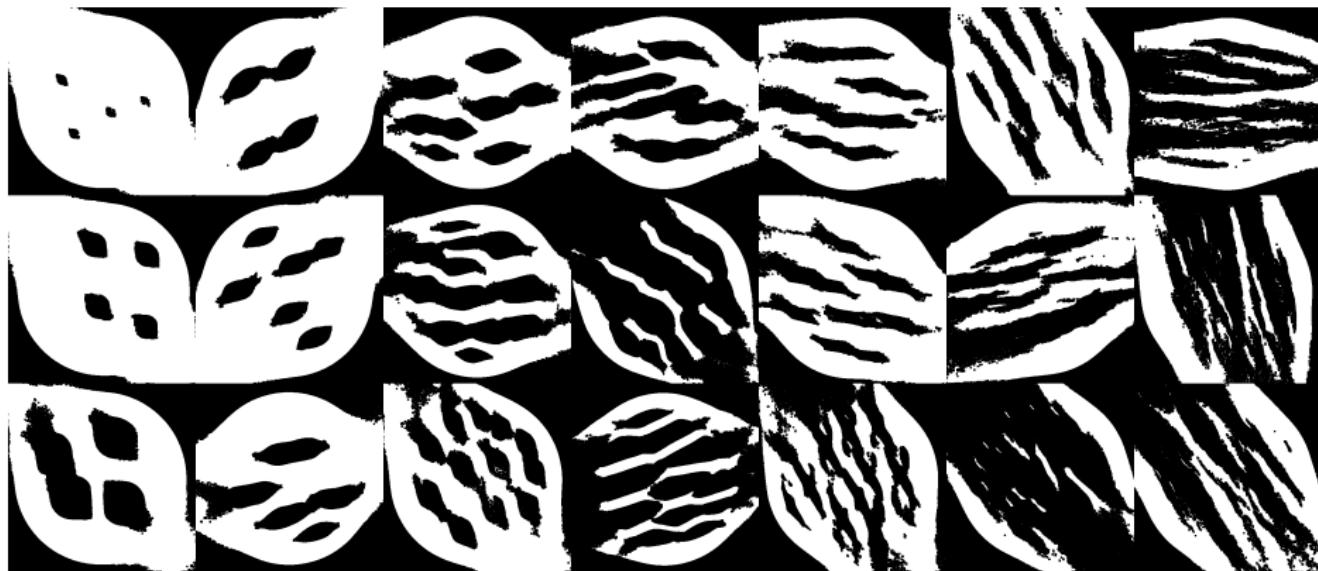
Shown are segmented FBP reconstructions from full-angle data

We measured full-angle X-ray data of the discs using our lab in Helsinki



Shown are segmented FBP reconstructions from full-angle data

The difficulty of reconstruction was raised by limiting the angle of view step by step



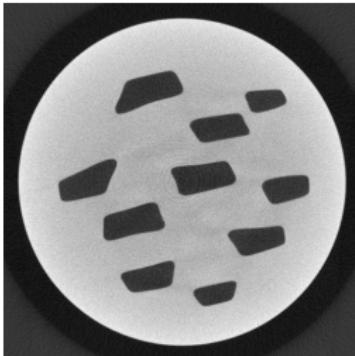
Shown are segmented FBP reconstructions from limited-angle data.
Angular ranges were $90^\circ \rightarrow 80^\circ \rightarrow \dots \rightarrow 30^\circ$

Helsinki Tomography Challenge 2022: phantom difficulty groups

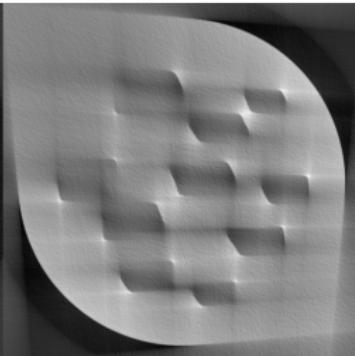
Group	Angular range	Angle increment	Number of projections
1	90°	0.5	181
2	80°	0.5	161
3	70°	0.5	141
4	60°	0.5	121
5	50°	0.5	101
6	40°	0.5	81
7	30°	0.5	61

Limited angle tomography is difficult

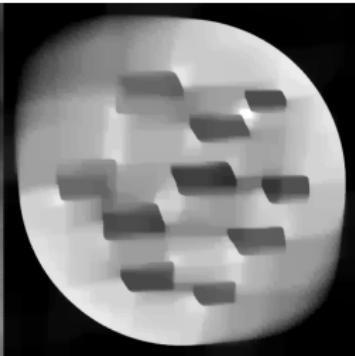
Full angle FBP



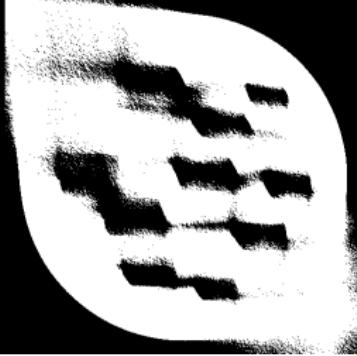
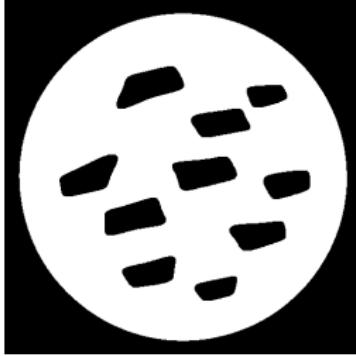
Limited angle FBP



Limited angle TV



Original



Segmented



See [Greenleaf & Uhlmann 1989], [Quinto 1993], and [Frikel & Quinto 2013]

Ground truth

Winner

FBP



The Helsinki Tomography Challenge 2022

9 participating teams from 7 countries:

- Austria
- Brazil
- China
- Denmark
- Germany
- India
- Singapore

Altogether 22 different algorithms were submitted.

Scoring the quality of reconstructions

Reconstructed binary image is I_r , ground truth binary image is I_t .
The score of the reconstruction is given by the Matthews correlation coefficient (MCC). Define

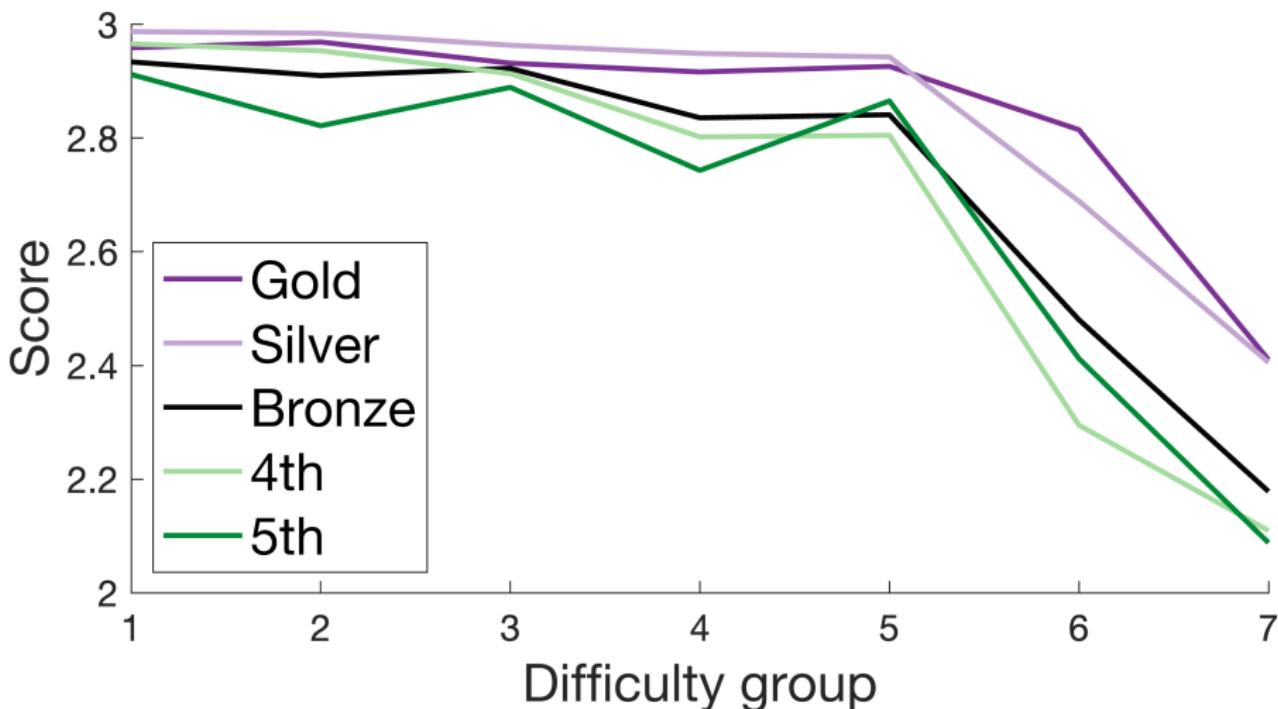
$$\begin{aligned} TP &= \sum_{i,j} (I_t \cap I_r)_{ij}, & FP &= \sum_{i,j} (\bar{I}_t \cap I_r)_{ij}, \\ FN &= \sum_{i,j} (I_t \cap \bar{I}_r)_{ij}, & TN &= \sum_{i,j} (\bar{I}_t \cap \bar{I}_r)_{ij}. \end{aligned}$$

Calculate MCC score $S \in [-1, 1]$ as

$$S = \frac{TP \times TN - FP \times FN}{\sqrt{(TP + FP)(TP + FN)(TN + FP)(TN + FN)}}.$$

A score of +1 (best) represents a perfect reconstruction, 0 no better than random reconstruction, and -1 (worst) indicates total disagreement between reconstruction and ground truth.

The scores of the five best teams in HTC2022



The Helsinki Tomography Challenge 2022

The top ranking teams are:

1. T Germer, J Robine, S Konietzny, S Harmeling and T Uelwer (TU Dortmund); H Heine (University Düsseldorf).
2. A Denker, C Arndt, J Nickel, J Leuschner, J Godeke, and S Dittmer from University of Bremen (ZeTeM).
3. G Fardell, J S Jorgensen, L Murgatroyd, E Papoutsellis, and E Pasca from DTU, Denmark.

The full results are viewable at

https://fips.fi/HTC2022_results.pdf.

All the data and participating algorithms are openly available.

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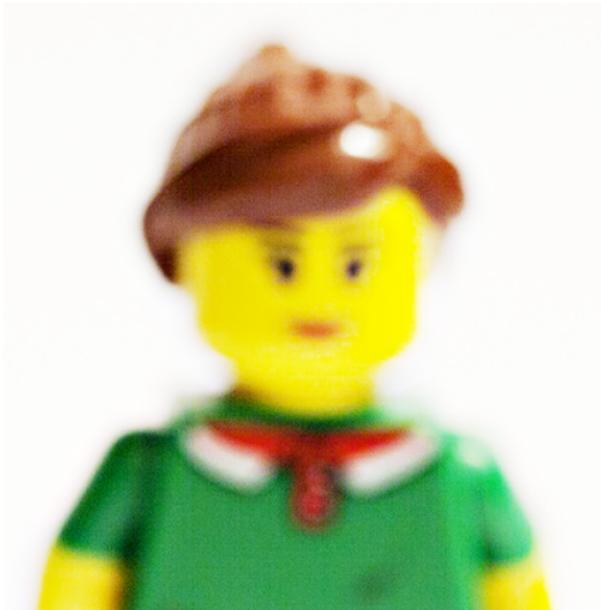
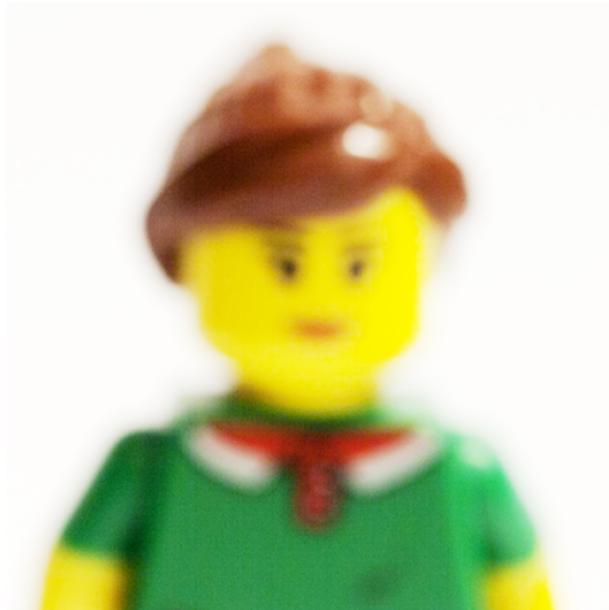
Joskus valokuvan tarkennus menee oikein



Joskus valokuvan tarkennus menee pieleen



**Voimme kokeilla Photoshopin komentoa
nimeltä *unsharp mask***



Tässä on toisen perusmenetelmän tulos



Uudenaikaisempiakin menetelmiä on, tässä
kokonaisvaihtelutemppu (Total Variation, TV)

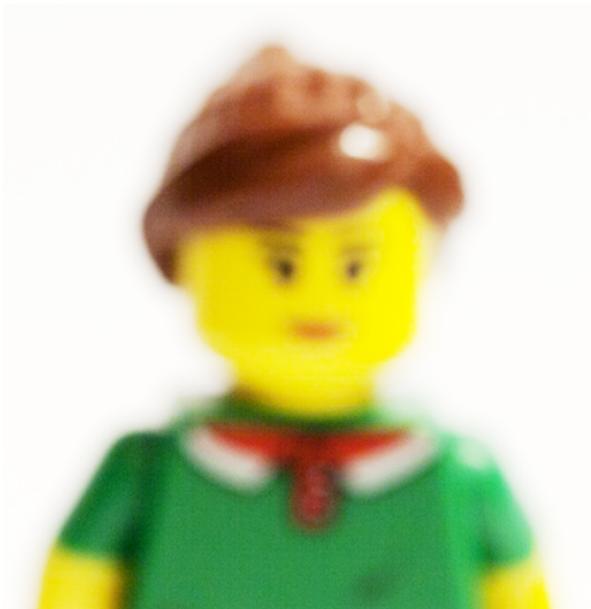


TV-menetelmän parannus TGV vähentää värien häiritsevää porrastumista



Kiitokset professori Kristian Brediesille TGV-koodin jakamisesta!

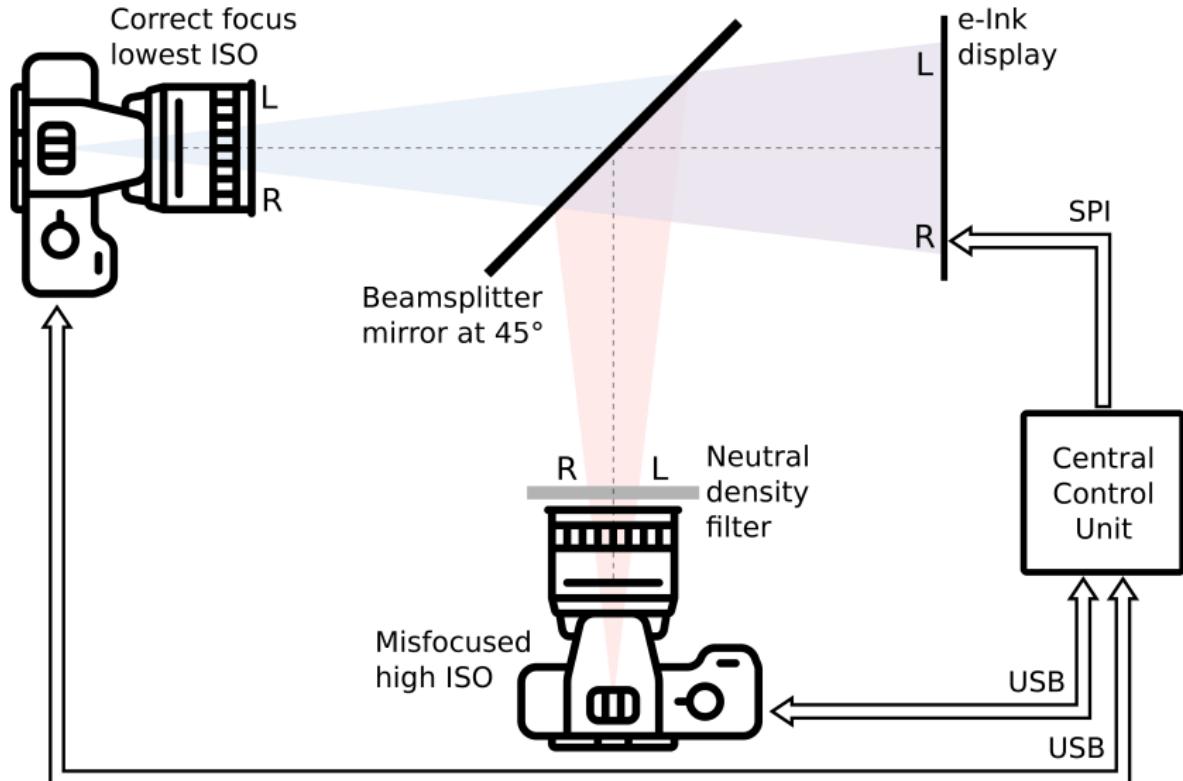
Viimeisintä huutoa oleva kaupallinen tekoälysofta tekee tälläista jälkeää



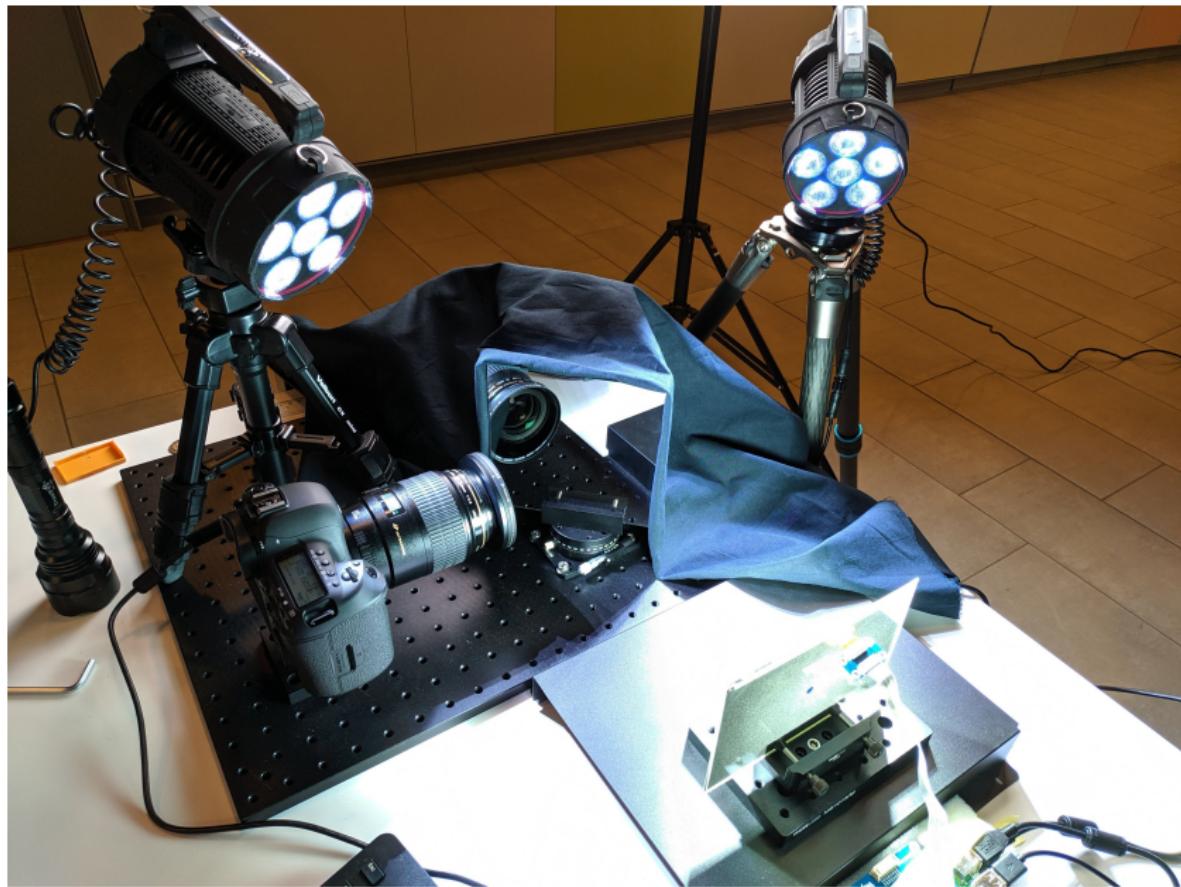
Kehitimme tutkimusryhmäni kanssa kuvien tarkennuskilpailun

HDC2021
HELSINKI DEBLUR CHALLENGE 2021

Tässä mittalaitteemme







OVOXq3AQ7D
WWHWSdeNKB
NHZYKdLoBr

Otimme kuvapareja yhä huonommin tarkennettuna

STEP 1	qgBus3nN9L 2cXuPSKPVP NsSkeWWfA	qgBus3nN9L 2cXuPSKPVP NsSkeWWfA
STEP 3	PH8KfUpLrA fufyG6udMG s8s X7gP2y	PH8KfUpLrA fufyG6udMG s8s X7gP2y
STEP 5	w5D28QeNeL J98kFGdmP7 xN5f3T378	w5D28QeNeL J98kFGdmP7 xN5f3T378
STEP 7	4fdJF e8SV qdsNku2pW4 WLPYRZ5nCf	4fdJF e8SV qdsNku2pW4 WLPYRZ5nCf

STEP 5

598kF GmHf ,
xN5f3T378

4763F e8SV
xN5f3T378

STEP 7

4fdJF e8SV
qdsNku2pW4
WLPYRZ5nCf

4763F e8SV
qdsNku2pW4
WLPYRZ5nCf

STEP 9

yK4pjYyPQe
xkvumuQDPW
wmHjrN EqE

yK4pjYyPQe
xkvumuQDPW
wmHjrN EqE

STEP 11

pvVpT8h Z
W27uJ4dQfu
ETNN8rTZhb

pvVpT8h Z
W27uJ4dQfu
ETNN8rTZhb

STEP 13

tuqxjiYzk8
FFkyG4Fsvg
DybTjdhVK4

tuqxjiYzk8
FFkyG4Fsvg
DybTjdhVK4

ETNN8rTZhb

STEP 13

tuqxjiYzk8
FFkyG4Fsvg
DybTjdhVK4

STEP 15

CsbakHQwDx
fQnJYAwXSL
MGRj84LXKs

STEP 17

rN2P Ayjz
zwJpcRRmdF
FmUTjEcwwP

STEP 19

BcsWr xNEn
kR3DMmvqTN
nB5Kk25jBT

Tulokset

Team	step 0	step 1	step 2	step 3	step 4	step 5	step 6	step 7	step 8	step 9	st
15_A	95.62	95.30	94.83	94.75	94.53	97.03	94.03	96.25	93.12	95.80	9
15_B	95.97	94.40	94.45	95.53	94.53	97.78	95.55	96.40	94.33	95.70	9
12_A	95.95	94.80	94.90	96.03	94.78	95.95	92.85	92.83	91.15	91.72	9
12_B	95.65	95.08	95.40	95.62	94.75	96.50	92.62	93.80	92.62	91.97	8
01	96.28	95.22	95.40	96.28	94.92	96.12	91.75	93.28	91.65	91.75	8
11_A	94.90	95.25	90.70	93.03	37.33	88.40	77.28	82.00	73.62	65.30	4
11_B	88.67	81.38	80.80	88.20	91.03	90.25	84.30	80.08	77.55	76.35	7
11_C	93.15	90.28	92.60	93.67	92.22	94.65	87.78	85.67	81.25	79.85	7
06	96.28	95.28	95.50	96.30	96.40	97.03	94.33	91.97	85.92	73.80	7
13	95.42	93.80	93.92	89.67	91.45	92.12	71.12	80.90	67.12	63.85	5
16_A	94.53	93.78	92.05	92.35	76.90	84.65	46.02	69.12	64.45	58.27	3
16_B	95.10	95.65	96.15	93.60	90.20	88.38	76.45	65.53	68.35	19.27	4
04	95.53	94.97	94.03	91.40	82.45	76.83	68	66.30	62.85	39.55	2
09_A	95.53	94.22	94.22	69.03	16.40	9.65	6.83	1.55	6.05	3.70	1
09_B	95.50	94.60	93.65	63.42	16.15	12.38	6.33	2.55	2.27	3.42	2

* Following the rules in case of category tie, the one with the highest

Tulokset

step 10	step 11	step 12	step 13	step 14	step 15	step 16	step 17	step 18	step 19	stop
93.75	91.55	91.42	92.00	87.15	77.50	89.00	81.97	80.85	71.65	19
92.97	92.80	91.65	93.22	86.28	73.60	89.50	81.35	79.97	69.88	
90.20	86.72	87.58	83.03	81.17	78.50	62.73	53.60	53.12	28.65	
85.80	83.50	85.95	85.72	82.97	84.15	77.80	72.33	71.80	61.38	18
88.67	88.83	87.12	87.55	84.88	18.02	82.47	70.30	71.00	67.17	14
42.90	52.75	3.50	0.00	43.88	6.42	0.00	1.93	2.23	0.68	
72.62	67.25	68.60	61.95	62.35	46.92	41.40	36.00	32.23	25.95	
79.15	67.08	62.80	60.83	54.23	32.60	36.35	23.05	21.88	21.75	10*
70.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10*
54.38	55.00	64.83	65.47	52.35	20.15	25.68	14.22	6.58	4.67	07
35.83	29.45	19.20	17.45	9.05	5.55	1.50	0.00	0.00	0.00	
4.03	13.50	7.42	3.80	2.48	0.00	0.00	0.00	0.00	0.00	06
24.38	13.82	10.70	5.95	3.30	1.43	0.00	0.00	0.00	0.00	05
1.70	3.05	1.62	1.55	0.33	2.90	2.85	3.73	7.62	3.62	
2.62	1.52	4.03	5.55	1.27	2.92	2.20	1.95	5.83	2.42	02

Best percentage in the stop category wins.

Voittajajoukkueen tyylinäyte tasolla 19

Ug KFEn8a
wBhsuUXGWV
z6PN3xufPe

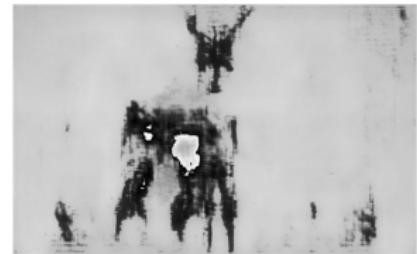


Ug KFEnIrt
wBhsuUXGWV
z6PNJxetdPv

Results of HDC2021

- ▶ 1st place: Theophil Trippe, Jan Macdonald & Maximilian März from TU Berlin and Martin Genzel from Utrecht University.
- ▶ 2nd place: Ji Li, Department of Mathematics, National University of Singapore.
- ▶ 3rd place: Daniël M. Pelt, LIACS, Leiden University, Leiden, The Netherlands.

Testikuvakin onnistui voittajilta



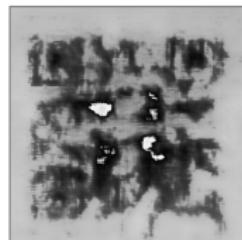
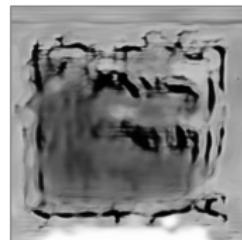
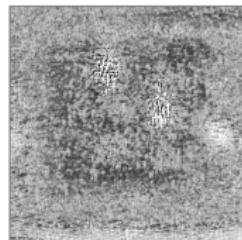
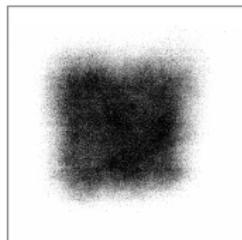
Ground truth



Blurred data



Reconstructions by Helsinki Deblur Challenge 2021 participants



Thank you for your attention!



← Slime mold called *Lycogala conicum*

Thank you for your attention!

